International Journal of EXERCISE SCIENCE

Original Research

Hip Flexion Angles During Supine Range of Motion and Bodyweight Squats

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ABSTRACT

International Journal of Exercise Science 14(1): 912-918, 2021. During the lowering phase of a squat, it has been observed that a posterior pelvic tilt (PPT) may occur when squatting to full depth. Research suggests that defaulting to compensatory movement strategies, such as PPT, during the squat may correlate with risk of lower extremity and trunk pathology. The purpose of this study was to examine hip flexion (HF) angles at the point when PPT occurs among three conditions: standard squats, heel raise squats, and supine passive HF; analyzing the differences in depth between standard and heel raise squats; and calculating differences in knee angles and ankle excursion between standard and heel raise squats. 28 participants performed bodyweight squats and underwent supine passive HF while outfitted with 32 retroreflective motion capture markers. Hip, knee, and ankle joint angles were extracted at the point of PPT. A one-way repeated measures ANOVA was used to determine differences in hip joint angles between conditions, and a paired sample t-test was used to compare knee angles, ankle excursion, and squat depth between standard and heel raise squats. HF angles at PPT remained unchanged across all conditions. However, significantly greater knee flexion, ankle excursion, and squat depth were observed in the heel raise squats compared to the standard squats. Results suggest that PPT is a compensatory movement that occurs as the femur compresses into the acetabulum once hip flexion has been exhausted.

KEY WORDS: Ankle excursion, heel raise, posterior pelvic tilt, squat depth

INTRODUCTION

The squat is a movement often employed in resistance training and athletics. In resistance training, the squat is used to develop strength and hypertrophy in the quadriceps and hip extensors (1, 3, 17). In athletics, it serves the purpose of executing positional and movement requirements for a given activity e.g., a hockey goalie or football linemen moving into or from a squat stance (14).

The lowering phase of the squat involves flexion of the hip and knee, and dorsiflexion of the ankle. It has been observed that at end range hip flexion (HF) during the squatting movement, the pelvis will begin to rotate posteriorly (2, 5). It is postulated that this pelvic rotation or posterior pelvic tilt (PPT) results due to an inability to increase depth through femoral motion alone. Therefore, in order to further descend, the pelvis must rotate. Regardless of setting, it is imperative that the effort to achieve a certain squat depth does not induce injury. Research suggests that defaulting to compensatory movement strategies, such as PPT, may correlate with risk of spinal and/or hip pathology (4, 10, 17). Increasing squat depth after PPT has been initiated causes the lumbar spine to flex and decreases the moment arm of the lumbar erector spinae. This minimizes the muscles' ability to withstand shear and compressive forces, potentially causing a greater risk for spinal injury (4, 6, 17). In addition, it is important to consider the implications that squat depth may have on the hip. At end range HF during the squat, contact between the femoral head and the acetabulum increases, which in turn could initiate structural changes associated with hip pathology, i.e., femoral acetabular impingement (FAI) (7, 9, 10, 19).

Evidence describing the interaction between hip flexion, pelvis motion, and squat depth is incomplete. A greater understanding of end range HF mechanics may assist in optimizing movement strategies for deep squatting. Therefore, the purpose of this experiment is threefold. First, to examine the HF angles at the point when PPT occurs among three conditions: standard squats, heel raise squats, and supine passive HF. Second, to analyze the differences in depth between standard and heel raise squats. Finally, to evaluate differences in knee angles and ankle excursion between standard and heel raise squats. It was hypothesized that there would be no differences in HF angles at PPT during standard squats, heel raise squats, and supine passive HF. Additionally, we hypothesized that squat depth would be greater during the heel raise squats when compared to the standard squats. Lastly, we hypothesized that knee flexion angles and ankle excursion would be greater in the heel raise squats compared to the standard squats.

METHODS

Participants

Based on an a-priori power analysis (power of 0.80, effect size of 0.5, p=0.05), twenty-eight college-aged participants, free from medically diagnosed spinal and/or lower extremity pathology, were recruited for the cross-sectional study (Table 1). All subjects read and signed an informed consent form approved by the Azusa Pacific University's Institutional Review Board. This research was carried out fully in accordance to the ethical standards of the *International Journal of Exercise Science* (12).

Table 1. Subject characteristics, mean (SD).

Characteristic	*n = 28*
Age (years)	20.89 (1.47)
Height (m)	1.70 (0.11)
Mass (kg)	67.63 (10.37)
Sex	14 male/14 female

Protocol

Participants were outfitted with 32 retroreflective motion capture markers, attached bilaterally to the participants' iliac crest, anterior superior iliac spine, posterior superior iliac spine, medial and lateral femoral epicondyles, medial and lateral malleoli, calcaneus, and base of the first and fifth metatarsals. Clusters of four rigid body markers were attached bilaterally to the thigh and shank.

Subjects performed supine passive HF (Figure 1A) and two types of bodyweight squats (Figures 1B and 1C). Supine passive HF was produced by a researcher who moved each limb unilaterally into full range HF, while also flexing the knee. Each leg was tested for four repetitions, and all repetitions were averaged for analysis. The researcher facilitating the protocol remained consistent between subjects.

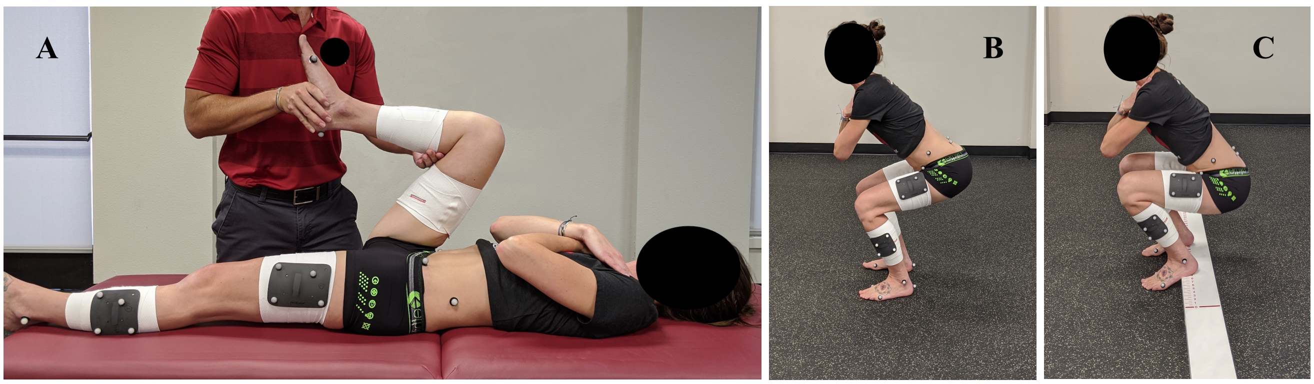

Figure 1. A) Supine passive hip flexion. B) Squat side view. C) Heel raise squat side view.

Bodyweight squats were completed with feet in full contact with the floor and with heels elevated on a board measuring 4.5 cm in height. All squats were performed barefoot with toes pointed forward. In the heel raise repetitions, the participant's calcaneus was placed at the front of the board (Figure 1C). Stance width was defined as the distance between right and left 2nd digits of the foot, and standardized using the width of the pelvis from right to left anterior superior iliac spines. Participants were cued to squat to full depth while maintaining heel contact with the ground or board. Eight repetitions were performed at 60 bpm. Subjects descended, paused at the bottom, and ascended, each for one beat during the squat. Repetitions two through seven were averaged for analysis to ensure each participant was in a controlled, consistent rhythm. All three conditions were randomized to control for effect.

Kinematic data were sampled at 240 Hz via an eight-camera motion capture system (Qualisys AB, Gothenburg, Sweden) and filtered using a fourth-order, lowpass recursive Butterworth filter with a frequency cutoff of 6Hz. Marker position data were utilized to calculate joint angles using Visual 3D software (C-Motion Inc., Rockville, MD, USA). All joint angles were calculated as motion of the distal segment relative to the proximal using Euler/Cardan angles (*x-y-z rotation sequence*), with the exception of the pelvis, which was modeled as the motion of the pelvis relative to the lab. Bilateral hip (motion of the femur relative to the pelvis), knee (tibia relative to femur) and ankle (foot relative to tibia) joint angles were extracted at the point of PPT. Onset of PPT was defined as the frame in which the sagittal plane joint velocity of the pelvis (motion of the pelvis relative to the lab) exceeded $0°\cdot s^{-1}$for at least 30 frames of data. Squat depth was normalized to a percentage of participants' leg length, measured from the medial malleoli to the anterior superior iliac spine. Ankle excursion was calculated as the difference between the starting and ending ankle joint position achieved during the squatting trials.

Statistical Analysis

All data were tested for normality using the Shapiro-Wilk test and outliers were screened using boxplots. A one-way repeated measures ANOVA was used to determine differences in hip joint angle among conditions and a paired sample t-tests were used to compare knee angle, ankle excursion, and squat depth between standard squats and heel raise squats (α=.05). All analyses were conducted using SPSS Statistics 25 (IBM Corp., Armonk NY, USA).

RESULTS

The Shapiro-Wilk's test indicated that hip flexion angles at the point of PPT were normally distributed in each of the three conditions, and there were no outliers. A one-way repeated measures ANOVA revealed that there were no statistically significant differences in hip flexion at PPT among each of the three conditions in both the left and right limbs, p=0.827, p=0.121 (Table 2).

Table 2. Sagittal plane hip and knee joint angles at PPT, and ankle excursion, mean [95% Confidence Interval].

	Squat (n = 28)	Heel Raise (n = 28)	Supine Hip Flexion (n = 28)	p
Left Hip	110.30 [107.06-113.54]	110.77 [107.27-114.27]	110.83 [107.15-114.51]	.827
Right Hip	109.45 [105.93-112.97]	109.94 [106.39-113.49]	111.68 [108.08-115.28]	.121
Left Knee*	100.39 [94.66-106.12]	123.97 [119.00-128.94]		< .001
Right Knee*	100.14 [94.27-106.01]	123.56 [118.57-128.55]		< .001
Left Ankle*	25.86 [23.75-27.97]	34.73 [31.92-37.54]		< .001
Right Ankle*	24.56 [22.65-26.47]	33.24 [30.50-35.98]		< .001

Note. * denotes significant difference between conditions. Positive values indicate flexion (hip and knee) and dorsiflexion (ankle).

While knee joint angles were not measured in the supine condition, data were collected in the standard and heel raise squats (Table 2). A paired sample t-test was then used to determine whether there is a difference between knee joint angles across the two conditions, bilaterally. Results show a significant increase in knee joint angles in the heel raise squats, for both the left knee t(27)=7.526, p<0.05, d=1.42, as well as the right knee t(27)=7.554, p<0.05, d=1.43.

Table 3. Squat depth at PPT, mean [95% Confidence Interval].

Squat Depth	Squat (n = 28)	Heel Raise (n = 28)	p
Depth (%)	30.89 [27.45-34.33]	55.00 [51.60-58.40]	<.001

Note. Squat depth measured as a percentage of subject leg length

A paired sample t-test also showed a statistically significant increase in depth in the heel raise squats compared to the standard squats, t(27)=8.018, p<0.05, d=1.52 (Table 3). Ankle excursion was greater in the heel raise squats compared to the standard squats, in both the left ankle, t(27)=7.339, p<0.05, d=1.39, as well as the right ankle, t(27)=7.010, p<0.05, d=1.32 (Table 2).

DISCUSSION

The purpose of this study was threefold: to examine the HF angles at the point when PPT occurs among standard squats, heel raise squats, and supine passive HF; to analyze the differences in depth between standard and heel raise squats; and to calculate the differences in knee angles and ankle excursion between standard and heel raise squats. As was hypothesized, no differences were found in HF angles at PPT among the three conditions, and knee flexion angles, squat depth, and ankle excursion were greater in the heel raise squats than in the standard squats.

HF can be achieved by rotating the femur towards the pelvis, the pelvis towards the femur or via concurrent movement of both segments (13). Previous research has described HF as a coupled movement in which femoral rotation towards the pelvis in the sagittal plane is followed by PPT (2, 5, 18). Under this supposition, it has been presumed that both femoral rotation and PPT are integral components of the complete HF movement (2, 5, 18). However, our findings suggest that this current understanding of HF mechanics may be limited. We found no difference in HF angles at PPT among any of the three conditions, thus indicating that regardless of the manner in which HF was performed, the amount by which the femur was capable of rotating towards the pelvis remained unchanged. Therefore, we propose that HF is not a coupled movement comprised of femoral rotation and PPT. Anatomically, anterior pelvic tilt decreases the joint angle between the femur and pelvis (hip flexion), whereas PPT increases the joint angle between the femur and pelvis (hip extension). Thus, our finding suggests that PPT is a compensatory movement strategy that occurs after hip flexion range of motion has been exhausted, allowing for a continuation of squat depth.

While the squat is a popular exercise used in both performance and rehabilitation settings, those with symptomatic FAI may experience pain during the exercise. It has been shown that pelvic tilt influences the occurrence of FAI (15). That is, dynamic anterior pelvic tilt leads to an earlier occurrence of FAI, whereas dynamic PPT leads to a later occurrence of FAI. However, our result that HF angles at the point when PPT occurs remained unchanged across three conditions suggests that PPT observed during end range HF is passive PPT. Theoretically, this passive PPT occurs as the femur compresses into the acetabulum once hip flexion has been exhausted, driving posterior pelvic tilt.

When comparing squat depth at PPT between the standard and heel raise squats, a significantly greater depth was achieved in the heel raise squats. Our results showed an increase in knee flexion and ankle excursion during the heel raise squats, while HF angles at PPT were unchanged across conditions. Our findings are similar to those of previous studies that have found that a heel raise squat, typically achieved through the use of weightlifting shoes or a decline surface, increases the available range of dorsiflexion at the ankle, increases knee flexion, and reduces forward trunk lean (11, 16). The ankle joint is of particular importance, as reduced dorsiflexion mobility can lead to compensatory joint moments up the kinetic chain, potentially leading to injury (8, 17). In our research, increased depth during the heel raise squats was accomplished by the ankle starting in a plantarflexed position, providing more ROM at the joint prior to dorsiflexion being exhausted. This change in starting position also allowed for greater knee flexion during the movement prior to PPT. Additionally, we found that HF at PPT was consistent across all conditions, thus indicating that end range HF is in fact the primary driver of passive PPT. Increasing hip mobility, in particular HF, may be the best strategy for improving squat depth while also delaying the point at which passive PPT occurs.

One of the limitations to this current study is the homogenous sample of college-aged participants. This may explain the consistency of HF angles at PPT across all conditions. While we would expect populations of differing demographics, such as older populations or Olympic lifters, to have consistent HF angles at PPT among conditions, the value of mean HF angle may differ. Another limitation was the relatively small amount of instruction given to the participants as they performed both the standard and heel raise squats. The participants were cued to squat to full depth at a set cadence, while maintaining heel contact with the ground with feet facing forward. These parameters allowed us to control for a consistent squat position and pace across subjects. However, further investigation is warranted to explore changes in PPT with different hip and foot positions, squat speeds, as well as cuing of pelvic position. Finally, joint angles were calculated at the onset of PPT, and the rate of change in pelvic angle was not measured beyond PPT. Measuring joint and pelvic angles beyond PPT may be informative in better understanding the pelvifemoral rhythm.

In summary, HF angles at PPT remained unchanged among all conditions and it is likely that PPT is not a movement coupled with femoral rotation during hip flexion, but rather a passive and/or compensatory movement at end-range hip flexion. Further, despite consistent HF angles at PPT, knee flexion, ankle excursion, and squat depth increased in the heel raise squats compared to the standard squats.

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